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ABSTRACT

It has only been since the late nineteenth century that people have understood the mechanics of heredity and the discoveries of genes and DNA are even more recent. This booklet considers three aspects of genetics; time, space, and spirit. Time refers to a sense of history; space refers to geography; and spirit refers to life and thought. Several chapters on the history and concepts of genetics, a time line related to the concepts, a map of the important geography related to these concepts, a glossary of important terms, and a list of several study suggestions are included. (CW)

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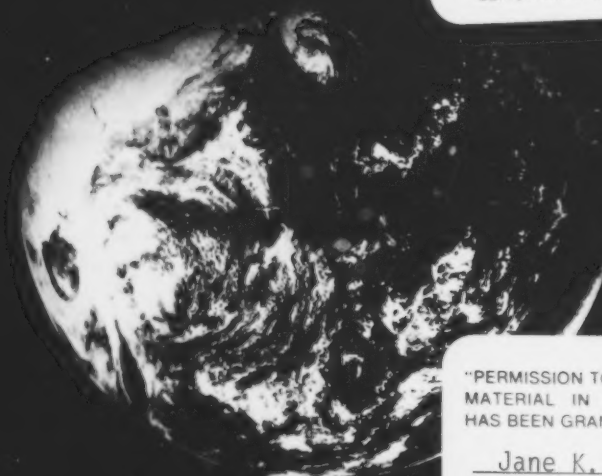
The Gene

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To the student,

This short book will help you better understand our modern world. It has changed a lot since your parents were born. Even more since you were born! And it will change still more--much more--in your lifetime.

What is behind most of these big changes? Two things. Science and technology.

What can you do about it? The first step is to understand more about science and technology and how they connect with our world. One way to do this--the way this book follows-- is to look at the world from three angles: Time, Space and Spirit.

Time means history. You can learn how science and technology have worked in the past, and are working today.

Space means geography. You can learn where important things happened in the past and are happening today.

Spirit means life. The life of the mind. You can learn the key words, concepts and ideas that power science and technology (and society) today.

This book teaches about science, technology and society from all three of these angles: Time, Space and Spirit. Read on.

The Gene

Bill Stonebarger
Illustrations by Lin Haley

Hawkhill Associates
Madison, Wisconsin

This book is one of a series of 16 Learning Power Books in the *Time, Space and Spirit: Keys to Scientific Literacy* series. It is designed to accompany the video program of the same name.

The *Time, Space and Spirit: Keys to Scientific Literacy* series was written and produced with consultation from the History of Science Department at the University of Wisconsin-Madison.

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Part 1: Monsters to Mendel to DNA



monsters

Monsters have a long and noble heritage. For centuries people believed that giraffes came from the mating of a camel and a leopard. If the camel mated with a sparrow instead, an ostrich was born.

In Russia people thought that very strong men sometimes came from a woman being kidnapped by a bear and conceiving child.

"freaks of nature" in the Renaissance

Besides the monsters people believed in but no one had actually seen, there were genuine monsters people had seen. In the Renaissance, particularly, there was a great interest in "freaks of nature," as they were called—two-headed calves, Siamese twins, babies with horns, and people with gross deformities.

heredity

Separating the make-believe monsters from the real monsters was difficult because no one knew much about heredity—that is, just how life's forms were passed on from parent to offspring.

From very early times people understood that sex was needed to produce offspring in the higher animals. They didn't think it was necessary for lower creatures, however.

no sex needed

Aristotle, the Greek philosopher and scientist—considered the greatest authority on science for over a thousand years—said that worms and flies and such were spontaneously generated out of muck and slime. No sex needed. No parents required.

Even when parents were obviously involved, no one had any idea what it was that made offspring resemble their parents. Nor what it was that made them a little different, too. In other words, no one had any idea how heredity worked.

story of the gene

Today we know how heredity works. We know what it is that makes offspring resemble their parents. It is genes. This is the story of how humans found out about genes. And the story of how genes work in our living world today.

Gregor Mendel

The first real scientific insight into heredity came over one hundred thirty years ago—about the time of our American Civil War—in a now-abandoned garden in Brno, Czechoslovakia. The breakthrough was made by an eccentric Catholic monk named Gregor Mendel.



Mendel was a busy man. He smoked twenty cigars a day, kept fifty hives of bees and many cages of mice, was regional weather correspondent for the Austrian empire,

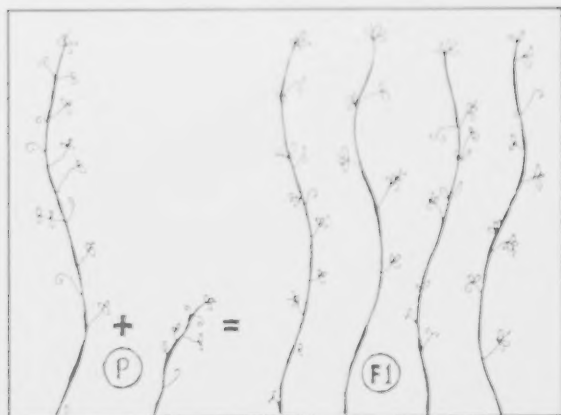
was elected abbot of his monastery, and carefully nurtured and studied thousands of garden pea plants. For this last task the world is forever in his debt.

blood inheritance

Up until Mendel's time even educated people thought that inheritance was somehow carried by the blood. They thought that offspring were a blend of the qualities of their parents. They even thought that if a man had a tattoo on his right arm, his child might also be born with a tattoo on his right arm.

experimenting with peas

Mendel's work with garden peas proved all these beliefs to be mistaken. Inheritance, he showed, was not carried by blood or any other general body cells of plant or animal. Instead, it was carried by some kind of special something that was hidden in the sexual cells, the egg and sperm cells. These special somethings were later given the name of genes.

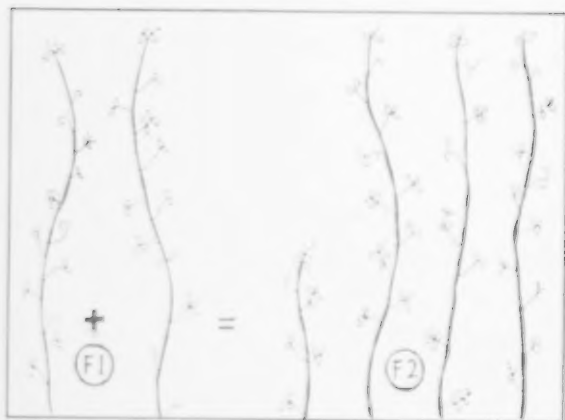


all tall stems!

Here is how he did it. In his monastery garden he experimented. He took the male cells of peas that produced tall-stemmed plants, for instance, and crossed them with the female cells of peas that produced short-stemmed plants. To his surprise, from this cross Mendel ended up not with a blend

of tall and short stems, but with all tall stems. One hundred percent tall stems? What had happened to the short-stem trait?

It had not blended. Had it been lost? Mendel did another experiment. He took the tall plants that he got from crossing tall and short plants (called the hybrid first generation plants) and crossed them with each other.



**short-stems
not lost**

Lo and behold, this time—the second generation—he did get some short-stemmed plants! In fact, on the average, one-fourth of the new pea plants turned out to be short-stemmed ones, and three-fourths turned out to be tall.

same ratios

Mendel got these same ratios when he tried six other simple characteristics—wrinkled and smooth seeds, axial and terminal flower buds, green and yellow seeds, yellow and green cotyledons, inflated and constricted pod shapes, and gray and white seed coats.

**not accepted
at time**

Some thought Mendel was a little odd to spend so much time counting seeds. When he published his results in the *Proceedings of the Brunn Society* in 1866 it did not make much of a splash. It was not

progress slow

until some forty years later, long after Mendel was dead, that the scientific world did take notice.

Today all biologists agree that Mendel's discoveries are indeed basic laws of heredity, valid not only for garden peas, but for elephants, for worms, for swordfish, and for humans.

After Mendel, progress was still slow in learning more details of heredity. And there was



backsliding as well. Despite Mendel's work, the great pioneer of evolution theory, Charles Darwin, still believed in blending. He also thought that traits picked up in the lifetime of plants and animals could be

inherited through what he called "gemmules" in the body cells of plants and animals.

"Don't waste your time ..."

As late as 1899 a student of biology at Brunn found Mendel's 1866 paper and eagerly showed it to his professor. "Oh, I know all about that paper, it is of no importance," said the professor. "It is pure Pythagorean stuff; don't waste your time on it."

One of the problems was that investigators were too ambitious. People like Francis Galton in England, for instance, carried out scores of ingenious studies on the inheritance of complex human traits like intelligence, size, and bodily strength. Galton even tried to develop numerical scales for beauty and love, and once did a statistical study of disasters on ships that carried missionaries versus those that did not.

All of these complex traits and happenings, we

know today, are due to a bewildering combination of thousands of genes and even more thousands of environmental factors.

August Weismann

Around the turn of the century, botanists were independently finding Mendel's laws to be true. One far-seeing German scientist, August Weismann, was already predicting in 1885 that heredity would eventually be found to be carried by "definite chemical, and above all, molecular structures." It remained for the twentieth century to discover just what that molecular structure is.

Crick and Watson

The most dramatic breakthrough in heredity since Mendel's garden happened on the banks of the Cam River in Cambridge, England in the 1950's. A



quiet young American biologist (and former Quiz Kid from Chicago), James Watson, used to stroll along the river path with an English biologist in his mid-30's, famous for his loud voice and even louder laugh—Francis Crick.

Crick said of Watson, "He was the first person I had met who thought the same way about biology as I did." Watson said of Crick, "He was the brightest person I had ever worked with."

at the Eagle Pub

Along this path, in a tiny office at nearby Cavendish Lab, and over long luncheons at the Eagle Pub, Crick and Watson puzzled about what genes were and how they worked. The place, the time, the spirit—all were ready—and the sparks from the combination led to the greatest revolution in biology since that of Charles Darwin's theory of natural selection a hundred years before.

Morgan & Muller

You see, by the 1950's much more was known about cells and about the Mendelian laws of heredity. T. H. Morgan at Columbia University and Hermann Muller at Indiana University had used fruit flies to locate genes on the chromosome. They had shown how Mendelian laws still apply, but in a more sophisticated way than Mendel had imagined.

mutation by x-ray

Muller, in particular, had shown how x-rays can cause mutations--that is, permanent changes--on a chromosome, on a gene. He was able to construct full-scale maps of the genes on the chromosomes of the fruit fly. A few decades later geneticists would

be able to do the same with human genes and chromosomes.



One of the most important keys in this progress was new and better scientific equipment. Microscopes, for instance, had become

better equipment

much more powerful. Using new x-ray diffraction techniques scientists could peek into the actual molecular structure of large molecules. New chemical techniques were invented--chromatography, electrophoresis, radioactive tracing--that could separate and identify unbelievably tiny amounts of complex chemicals.

Each one of these advances required the thought and work of many hundreds of researchers, so that it is misleading and unfair to single out one or two people to get all the credit. So too with the discovery of the molecular structure of genes that is now usually credited to the famous Crick and Watson team.

tools of the trade

The particular tools that Watson and Crick used to make the breakthrough were model-building, some recent x-ray data, and inspired guesswork. The principles needed for the model-building had been worked out across an ocean and a continent by the chemist Linus Pauling at the California Institute of Technology at Pasadena. The x-ray data had come from the work of two scientists in London, Rosalind Franklin and Maurice Wilkens. The guesswork was their own.

Rosalind Franklin



Later, three of the four received the Nobel Prize for the brilliant answer they gave to the question of what a gene is and how it works. Sadly, the fourth, Rosalind Franklin, died a premature death from cancer in 1964,

two years before the Nobel Prizes were awarded.

What exactly did Crick and Watson do?

architecture of DNA

They figured out the architecture of a very large molecule—deoxyribonucleic acid—DNA for short. This molecular structure was so important because it is DNA in the nucleus of all cells that is the actual physical thing that carries the all-important information of heredity. The special something that Mendel had assumed in pea plants. The molecule that Weismann had predicted in 1885. The gene that Muller had mapped on fruit fly chromosomes.

what is DNA?

DNA is the physical molecule that carries the computer-like code that tells your cells how to make an eye, an arm, a brain. And not just any eye, any arm, any brain, but your eye, your arm, your brain. And not just you, but your dog, your

goldfish, your poison ivy, your earthworm, the largest whale in our ocean, the smallest virus in our blood stream.

All living things, in other words, are built and operated following instructions from the DNA in their cells. Crick and Watson could now diagram and make models of the very most-secret heart of life itself!

paper in *Nature*

Here is the actual diagram Crick and Watson drew for their famous paper, "A Structure of Deoxyribose Nucleic Acid" in the scientific journal *Nature* of April 25, 1953.



DNA, they guessed correctly, was a double helix structure. The helix backbone was always the same, a well-known chemical group called phosphate sugar. Connecting the two phosphate sugar ribbons are pairs of four well-known chemical bases called adenine, cytosine,

the double helix

guanine, and thymine. To a chemist it was simplicity itself. And an elegant, beautiful simplicity! Especially when they saw that guanine can only connect to cytosine and adenine can only connect to thymine. Yet despite that limitation, the helix is long enough so that an almost infinite number of possible sequences is possible. Which means that an almost infinite variety of life forms is possible.

replication

And finally, as Crick and Watson said in their paper, "It has not escaped our attention that this double helix structure provides powerful hints as

to methods of replication within the cell." In Part 2 of this program we will show how simply that replication works. Again, an elegant, beautiful solution to an age-old puzzle.

Just finding the actual molecular structure of DNA did not in itself solve all the problems of genetics. It did provide, however, the most powerful tool yet found to investigate these problems. Now scientists could isolate the parts of the cell that were the sites of the actual physical genes. They could proceed to take these genes apart and put them back together again. In old ways, and in new ways.

rapid progress in genetics

And today in laboratories all over the world geneticists and biochemists are making rapid progress in deciphering life's codes in many plants and animals, including humans. Synthetic genes have been made. Genes have been spliced from one organism into another. Genes have been repaired. Genes have been mutated.

genetic engineering

Genetic surgery is now widely used commercially as hundreds of new biotech companies are launched. Whole new kinds of life forms--especially new strains of bacteria--are being designed and made in the laboratory. New kinds of life forms engineered to do specific tasks like create hormones, antibiotics, vaccines. Mine metals, clean up pollution, even build computers.

mapping all the human genes

And in one of the biggest scientific projects of all time, geneticists are right now mapping all the genes of the human species! This project is being led, fittingly enough, by James Watson himself. The past fifty years have indeed started a revolution in biology. The next fifty years will have their own surprises.

Part 2: What Is a Gene and How Does It Work?



Alice in Wonderland

"Alice laughed: 'There's no use trying,' she said. 'One cannot believe impossible things.'

"'I daresay you haven't had much practice,' said the Queen. 'When I was your age, I always did it for half an hour a day. Why, sometimes I've believed in as many as six impossible things before breakfast.'"

And if Alice could wander through the wonderland of modern genetics she would need even more practice. For here, at the heart of life, the impossible is an everyday thing.

power of DNA

Would you believe, for instance, that less than a teaspoon of a substance called DNA, deoxyribonucleic acid, would be enough to re-create all the people now living in this world?

Or how about this--before the end of the century we may be able to actually re-create you from the

information coded in the DNA of any one of your cells, say one microscopic cell from your big toe.

Right now, today, we can transfer a gene from one plant to another, from one animal to another. We can make a synthetic gene for rabbit hemoglobin. We can create new kinds of living bacteria. Some of these bacteria can mine copper for us, can make insulin and other hormones, can produce new antibiotics, can fix nitrogen into fertilizers, and someday soon may even be able to produce and reproduce living computers!

not science fiction

All of this is not science fiction. Scores of hard-nosed business people have invested millions of dollars in new high-tech companies springing up all over the world to make these impossible everyday realities.

basic science

Let's look at the basic science that makes all this possible. Just as knowledge of the atom is the most important key to understanding physics and chemistry today, so knowledge of the gene is the most important key to biology today.

What is a gene?

the code of life

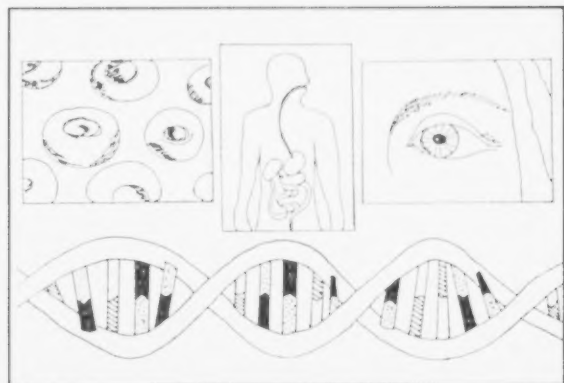
The gene, we know today, is a molecular structure that carries the code needed to govern life



functions. Just as a computer needs a program, so a cell (and a complex combination of cells called an organism) needs a program. That program is in code. The code is on a spiralling molecular

structure called deoxyribonucleic acid, DNA for short.

DNA and the gene



A single molecule of DNA actually carries more than one instruction, more than one gene. Along this spiralling molecule, for instance, one section might be the code that governs eye color. Another section could have the code needed to produce the hormone insulin. Another section would have the code for hemoglobin in your red blood cells.

many genes needed

Obviously, in order to create an entire person (or snake or oak tree) you need a lot of genes—many million, in fact. And these genes have complex interactions as well—billions and billions. The possible combinations get astronomical. How else could we have such a rich variety of living things in our world?

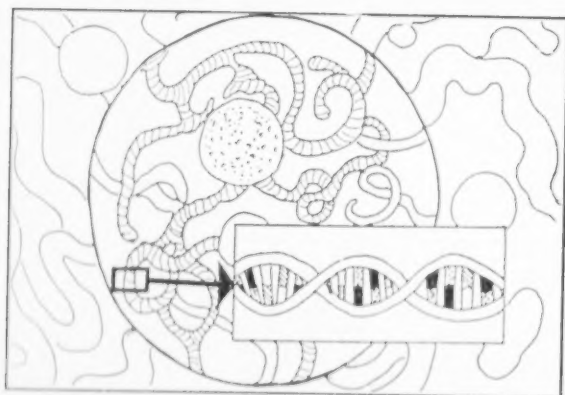
Think of all the possible combinations of magnetic pulses on a tape, grooves on a record, words in a book. DNA is like that, only more so. More information, more power.

genes and chromosomes

DNA molecules are surrounded by protective protein coats and strung like beads along structures called chromosomes. These chromosomes wind around in every cell's nucleus.

redundant nature

Each chromosome has many hundreds of DNA molecules; each DNA molecule has thousands of



genes. One surprise is that much of the DNA does not seem to carry any coded messages at all. We don't know at this time just why this should be so. Perhaps nature, like human beings, can be redundant and wasteful, as well as efficient and powerful.

cloning

Just about every cell in the living body of every organism has a store of DNA in its nucleus. The same store as in every other cell of the same individual organism. This is why cloning is possible.

Cloning has been known and practiced for many years by gardeners. Recently it has been done experimentally with animals, too, including mammals.

exactly same as parent

Cloning is a way to use the coded instructions of a general body cell to reproduce the whole organism without sexual recombination. Thus, the cloned individual turns out to be exactly like the parent in every respect—since he or she has exactly the same genetic instructions within each and every cell.

Normally, of course, this is not the way organisms reproduce.

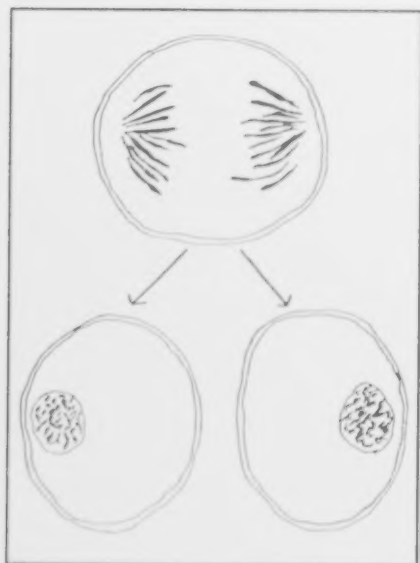
sexual reproduction

Normally, the genes that are going to be used to create a new organism are, very early along, segregated from other body cells. They are kept separate in the ovaries of the female (the eggs) and in the testes of the male (the sperms). Because they are segregated so early, experience of the adult organism has nothing to do with the heredity given to the offspring. Thus, inheritance of acquired characteristics is not possible.

meiosis

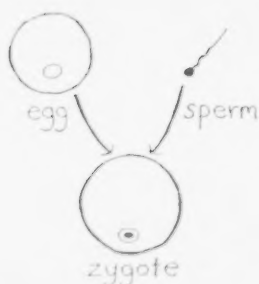
When it comes time to reproduce, cells in the testes and in the ovaries go through a special kind of

division called meiosis. In the diagram you see a microscopic view of what happens to the chromosomes in meiosis. They divide in two. Each sperm and each egg thus gets only one-half the regular number of chromosomes and genes. In your case, for instance, this means you got one-half of your inheritance from your mother and one-half from your father.



fertilization

When your parents had sexual intercourse, these half-number cells joined together to make a new whole-number cell--a fertilized egg. The egg from your mother and the sperm from your father, in other words, fused together to make one complete cell, a fertilized egg cell that in a few short months was born as a unique new person--you.



In those "few short months" came the impossible part, the part we still know so little about it does seem near miraculous.

The single fertilized egg cell had all the

a saltwater world

codes needed to create you. To let these codes do their job, all the fertilized egg cell needed was the right environment. Your mother's uterus provided this environment. It provided the right temperature and the right chemicals. It provided a saltwater world very similar to the ancient oceans where amino acids, sugars, salts, and fatty acids are abundant and ready for use.

mitosis

When all is right, the process unfolds like the most dramatic motion picture you have ever seen. The single fertilized egg cell quivers, doubles its chromosomes, and divides into two. This is called mitosis. Notice, it is different from meiosis in that the chromosomes (and thus the DNA and the genes) doubled before the cell divided into two. Thus each new cell has a full set of chromosomes, DNA, and genes.

DNA replication

Let's look at this doubling more closely. Remember how Crick and Watson put it in their epoch-making article, "It has not escaped our attention that this double helix structure provides powerful hints as to methods of replication within the cell." Here is what they meant and here is how it does work.

double helix ladder

The double backbone of the helix is made of phosphate sugar groups. These are connected—like rungs on a twisted ladder—by four different kinds of chemical bases—guanine, thymine, cytosine, and



adenine. Guanine, it turns out, can only hook itself to cytosine, and adenine can only bond with thymine. That is sufficient to create an intricate code, and to provide an ingenious way of replicating.

DNA unzips

With the help of other important chemical molecules called enzymes, the two backbone parts of the DNA molecule untwist, and then the whole molecule unzips. This gives two half-DNA molecules. But two halves with highly active base parts.

Here is where the environment comes in again. Floating in the saltwater soup of the cell are plenty of guanine, thymine, cytosine and adenine groups. Where did they come from? From the food the mother ate and supplied to the uterine environment.

DNA zips back up

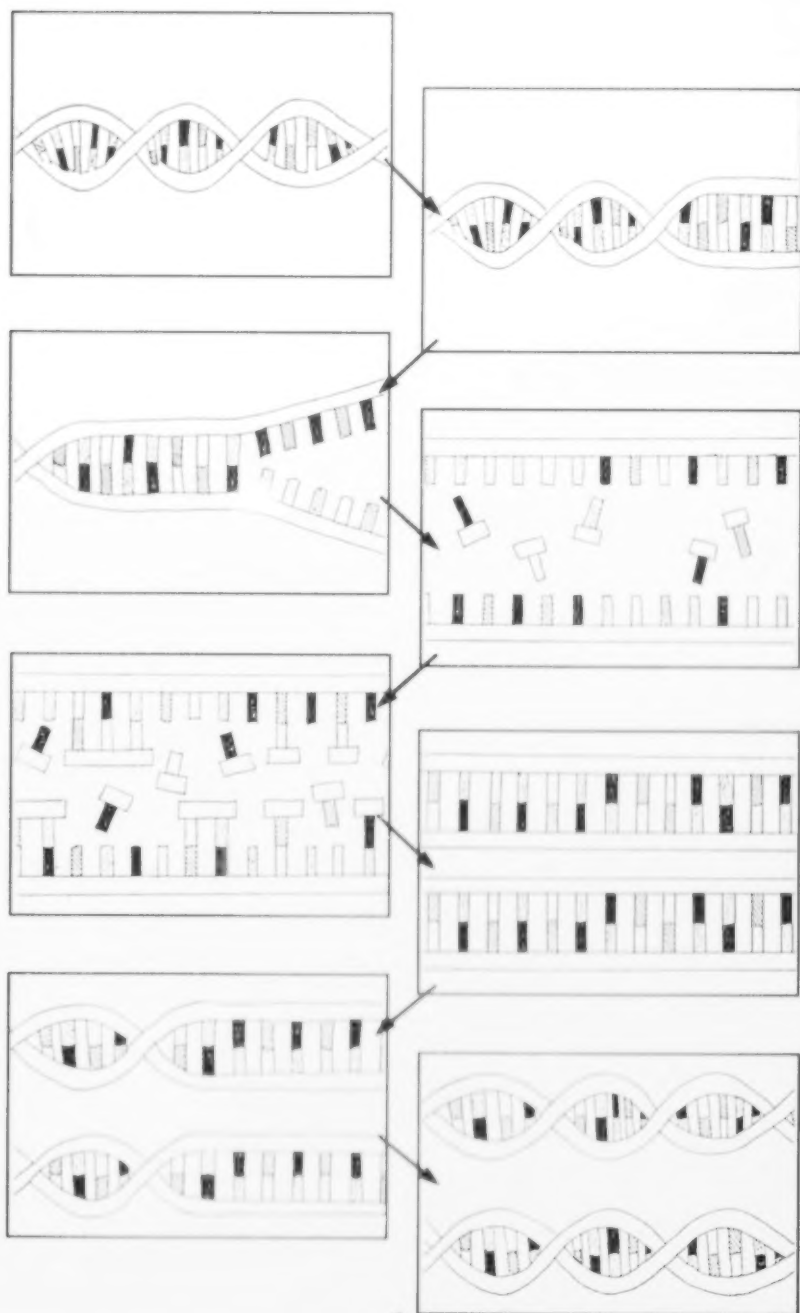
With the help of still other important enzymes, each half of DNA hooks onto the base group as needed. That is, every guanine hooks onto a cytosine, every adenine to a thymine, every cytosine to a guanine, and every thymine to an adenine. Phosphate sugars are also nearby and so we zip back up and now we have two DNA's where there was only one before. Two identical DNA's.

identical cells

The cell now divides, the chromosomes divide, the DNA's divide and you have two complete cells with two complete sets of code. Each cell identical to the one it came from.

more dividing

The process continues. Two become four, four become eight, eight become sixteen, sixteen, thirty-two, etc. etc. etc. And we get millions and billions of cells, all with the complete set of chromosomes, DNA, and codes to make you you.



But wait! How come the cells are not all alike then? The cells in your eye, for example, are not like the cells in your ear. The cells in your lungs are not like the cells in your biceps. How did they all become different?

For the most part, that is still a great mystery! No one knows. Not yet.

differentiation

This great mystery is given a name. It is called differentiation. There is a lot we don't know about differentiation. One thing we know is that it is governed by the genetic code on the DNA molecules. We also know a little about how the DNA code tells the rest of the cell what to do.

DNA to RNA

The DNA is able to pass along its coded messages to a very similar single chain molecule called ribonucleic acid, RNA. This smaller RNA molecule

is able to slip out of the nucleus into the rest of the cell. There it takes charge of the building of new enzymes and proteins. And finally, it is these enzymes and proteins that do the actual work of the cell. Carrying

oxygen, for instance, if you happen to be a red blood cell. Carrying electrochemical pulses if you happen to be a nerve cell. Contracting if you happen to be a muscle cell.

Amazing! Amazing that it does work and even more amazing that scientists have been able to decipher as much as they already have about how it does work.

Of course, it is one thing to read about this, and

another to actually figure it out in practice. Today there are many genetics laboratories all over the world cooperating and competing to push forward our basic knowledge of the gene.

how to experiment with DNA

The tools of all these scientists are similar. Some of the most basic are as old and common as any in science--test tubes, beakers, sterile culture dishes, pipettes, colored tapes, a variety of chemical reagents, bunsen burners, and refrigerators.

Others are newer and more sophisticated. Electron microscopes, electrophoresis set-ups, scintillation counters, ultra-high-speed centrifuges, and of course, ultra-fast computers.

chemical scissors

The techniques worked out to probe these submicroscopic genes are ingenious to say the least. For instance, suppose you want to cut a strand of DNA at a particular spot, say where the gene for eye color is located. No problem. Today there is a large variety of chemicals called restriction enzymes that can act as sharp and ever-so-accurate chemical scissors. You can buy these restriction enzymes off the shelf.

radioactive tracers

Other chemicals, usually radioactive tracers, are used to mark the points of cutting. Then various gels can be used in combination with electrical charges to separate the DNA fragments.



Once separated on a piece of paper or on a gel, a computer is brought in to help interpret the patterns found. The final result is a kind of photographic record of the sequences of thymine, guanine, cytosine and adenine pairs.

Whether on film or reprinted on paper, the sequences are very long. Geneticists today are a little like a child just beginning to read. They are still at the primer level. What will it be like when

we reach the length and sophistication of a *War and Peace*-length novel?

basic science of the gene

It's time to summarize the basic facts before we take a final look at the controversial future--the engineering of new life forms.

One. The gene is the biological unit that carries heredity in every cell of every living organism, from viruses to fruit flies, from pea plants to people.

Two. The gene itself is a molecular structure, a group of atoms that are part of a large molecule called deoxyribonucleic acid, DNA.

Three. It is the pattern of base sequences on the DNA that is the code which when translated by living cells make a virus a virus, a fruit fly a fruit fly, a pea plant a pea plant, and a human a human. Not only in general, but a particular virus, a particular fruit fly, a particular pea plant, a particular human being.

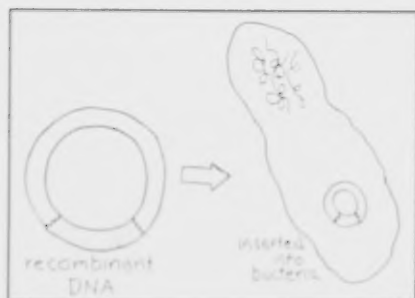
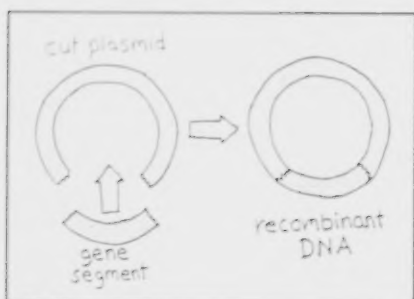
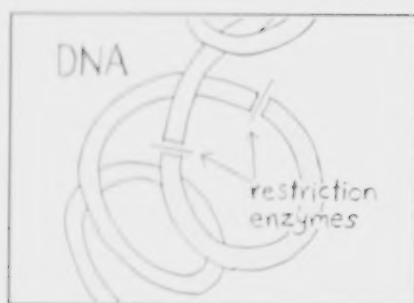
Four. When you change the structure of the DNA sequence, you change the code, you change the living tissue, you change the living organism. It's like changing the computer program, or the words in a book. You end up with a new program, a new book. Maybe better, maybe worse. In the case of genes in nature, the new living organism that results from a change in the gene (called a mutation) is usually worse off than its parent.

Five. Very occasionally a mutation may lead to a new trait in the offspring that is to its advantage. That offspring will have a better chance to survive and pass on that new mutant gene to its offspring. In this way change and natural selection will occur.

What does all this mean in practical life today?

recombinant DNA

For one thing, today humans are trying to engineer genetic changes for the good. They do this using what is called *recombinant DNA* technology.



Say you find a gene that is capable of some desired task--cleaning up oil spills, producing insulin, gobbling up some nasty toxic waste, fixing nitrogen into fertilizer, or whatever. Using one of the new restriction enzymes, you snip it out of the cell it is found in normally. Then you "paste" it into an opened-up cell in a fast-reproducing bacteria.

You give the newly enhanced bacteria enough food and living space and let it reproduce. Within a very short time you have billions on billions of these powerful new living things--living factories!

living factories

You purify the substances they have produced, bottle them, and sell them to people who need them.

Similar techniques are also being developed to "cut and paste" genes from one organism to another--

say from a bean plant into a corn plant, or from a bacteria into a rabbit.

**damage in
the web
of life?**

As always with new knowledge, there are risks as well. What if some of the new human-created germs escape the factory or the laboratory and play havoc with natural genes--our own or other natural creatures in the web of life?

Will the imaginary monsters of the past become only too real this time. And will the real monsters multiply beyond our control and our worst nightmares become reality?

a new age

Or will we enter into a new era where our farms and orchards are more fruitful, our factories and mines safer and more productive, our cities and our countryside freed of pollution, and all of our people--all the world's people--freed from inherited diseases, free to live longer, healthier, and happier lives.

**a role
for you**

All of these possibilities and more are being actively studied and debated today. Now that you understand the basic principles of this new genetics, you, too, can take a role in the debate. For in the long run, in a democracy like ours, how this immense new power is used is up to the most important people in the world--you and me.

TIME ...

To understand the world of today it helps to know something about the world of yesterday. Kings and queens, wars and famines, presidents and paupers have all played a part. But more important than any of these in changing the past world into the world of today has been science and technology. The time line below will help you better place important events and people in historical time.

EVENTS IN WORLD HISTORY

1776
American Revolution

1800

1861-65
Civil War

1914-18
World War I

1939-45
World War II

1966-73
Vietnam War

EVENTS IN SCIENCE & TECHNOLOGY

1800

1831-36
Darwin's world trip

1854-65
Mendel's garden

1880
Edison's first electric light

1893
Henry Ford builds first auto

1900

1945
Muller wins Nobel Prize for
work on x-ray mutations

1953
Crick and Watson publish
paper on DNA structure

1975-today
recombinant DNA work

SPACE ...

There is a saying, "If you don't know where you are going, any road will get you there." One of the important parts of knowing where you are going is a knowledge of geography. The map below will help you to better locate the important events and people discussed in this book.



**1. Brno,
Czechoslovakia**

Monastery where Gregor Mendel lived and worked. In Mendel's day Brno was part of the Austro-Hungarian Empire. Today Czechoslovakia is a communist country. Marxist theory has often been used to try to discredit Mendelian genetics. Perhaps for that reason Mendel's monastery is today in disrepair and Mendel is not widely known or honored in his home town and country.

**2. Cambridge
University,
Cambridge,
England**

Francis Crick and James Watson worked out the structure of DNA here. Cambridge University has been one of the leading centers for scientific and humanistic research since the 13th century. Isaac Newton and Charles Darwin were both educated here.

**3. London,
England**

Charles Darwin took a famous voyage around the world from 1831 to 1836 as an unpaid naturalist on the H.M.S. Beagle. For the rest of his life he lived in a country home at Down, a few miles southeast of London, where he wrote his classic work, "Origin of the Species."

SPIRIT ...

Time and space are meaningless without spirit. Spirit is the part in each of us that understands. The part that sees connections between words and things--connections that surprise and make sense. Study the key words, concepts, and ideas below so that you can better understand how time, space, and spirit worked in the past--and are working today.

- amino acids** A group of chemical compounds that are the building blocks for proteins in living things. (p. 16)
- Aristotle** Greek philosopher and scientist who was looked on as the last word in science for over a thousand years. (p. 2)
- bacteria** Microscopically small living things of only one cell. Some are harmful, most are harmless, and many are essential to the life of other organisms, including humans. (p. 10, 12, 23)
- biochemist** A scientist who specializes in the chemistry of living things. (p. 10)
- chromosomes** Microscopic thread-like structures in the nuclei of all cells that contain DNA molecules and play a key role in both cell metabolism and reproduction. (p. 7, 13, 15-16, 18)
- cloning** Reproducing an organism without sexual recombination using body cell(s) from the parent organism. (p. 14)
- differentiation** A process in the embryo where cells become different even though descended from the same egg cell. (p. 20)
- DNA** Short for deoxyribonucleic acid, a large organic molecule that contains the genetic code. (p. 8-14, 16, 18-22)
- double helix** A molecular structure easier drawn than described (p. 9).

enzyme	Large organic molecules in living cells that play key roles in just about all of the cell's activities. (p. 18, 20)
evolution	The process of change in living things over periods of time (generally very long periods of time). (p. 5)
gene	The carrier of heredity code, a section of a DNA molecule in the nuclei of all cells.
genetics	The science of heredity.
heredity	The passing along of living traits from parent to offspring.
meiosis	Cell division in the ovaries and testes whereby sex cells (eggs and sperms) are made, each with only one-half the usual number of chromosomes and genes. (p. 15)
mitosis	Cell division in living bodies, plant and animal, whereby each daughter cell has the same number of chromosomes and genes as parent cell. (p. 16)
molecule	Group of two or more atoms that bond together.
mutation	A permanent change in the genes of a living organism. (p. 7, 22)
natural selection	Darwin's theory of evolution--in the struggle for existence nature chooses which organisms are most fit to survive. (p. 22)
ovary	The organ in females that produces the egg. (p. 15)
protein	Large organic molecules that together make up the structure of living things.
restriction enzyme	Special organic molecules that have the ability to cut DNA segments at specific points. (p. 21, 23)
RNA	Large organic molecule that carries the genetic code out of the cell's nucleus into the cytoplasm. (p. 20)



sexual reproduction

Nature's way of assuring variety in offspring. (p. 15)

testis

The organ in males that produces sperm. (p. 15)

uterus

The female organ wherein the embryo is nurtured until birth. (p. 16)

x-rays

Radiation that can cause mutations in living things. (p. 7)

In addition to the above, THE GENE also teaches about other important people, places, things, and ideas. Often you can figure out the meaning of a new term by seeing how it is used in context. Make sure you know the meaning of the following (for help, check the pages listed in this Learning Power Book, as well as your dictionary and encyclopedia):

adenine (p. 9, 16-18); Alice in Wonderland (p. 11); antibiotic (p. 10); cells; computer program; cytosine (p. 9, 16-18); electrophoresis (p. 21); environment/heredity dispute (p. 5-6); egg cell (p. 15); fertilized egg cell (p. 15); Franklin, Rosalind (p. 8); guanine (p. 9, 16-18); hemoglobin (p. 12-13); hormone (p. 10); inheritance; insulin (p. 23); monastery; monk; nucleus of cell; Pauling, Linus (p. 8); phosphate sugar (p. 9, 16-18); physics; radioactive tracers (p. 21); ratio (p. 3-4); red blood cells (p. 13); Renaissance (p. 1); Russia; sperm cell (p. 15); spontaneous generation (p. 2); synthetic (p. 12); thymine (p. 9, 16-18); vaccine (p. 10).

STUDY SUGGESTIONS ...

1. Both pea plants and fruit flies have played important parts in genetics research. Both are relatively easy to culture in school laboratories or at home. Try replicating some of the historic experiments. Go on to new ones of your own invention.
2. Pioneers in science are sometimes, as in Mendel's case, ignored for years after their important discoveries are made. A modern example is the geneticist Barbara McClintock, who first proposed a theory of "jumping genes" in the 1940's. In 1983 she won a Nobel Prize for her work. Read about her work and discuss.
3. Recombinant DNA technology has triggered strong objections from some quarters today. Critics claim it threatens our environment (and us) with irreparable harm. Supporters say the risks are minimal and the prospects for good are enormous. Study the issue yourself and hold class debate. Good source for background information is *The DNA Story* (see bibliography below).
4. There has been a good deal of controversy over the place of Rosalind Franklin in the DNA breakthrough. It would make a good subject for a library research project.
5. There has also been dispute about James Watson's book, *The Double Helix*. Some were offended by his outspoken evaluations of fellow scientists. Read Watson's book and discuss.

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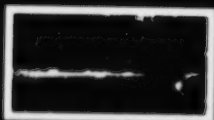
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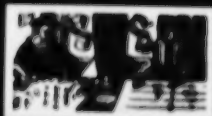
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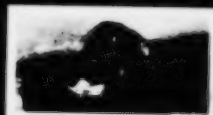
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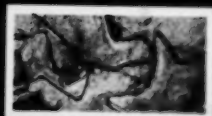
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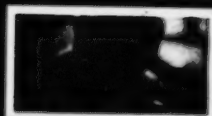
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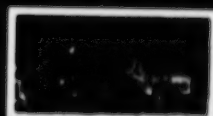
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